F.R.Note No. 475

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

SITING OF HEAT-SENSITIVE FIRE DETECTORS IN BUILDINGS

by

D. Hird, R. H. Bigmore and R. W. Pickard.

Summary

This report describes experimental measurements of the temperatures and velocities of hot gases rising from a fire and spreading beneath the ceilings of various types of buildings. From the results, the general principles underlying the siting of heat-sensitive fire detectors are deduced.

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1. Introduction.

A system of heat-sensitive fire detectors in a building is required to give warning of a fire at an early stage in its development, so that the occupants may safely leave and the fire brigade may be called before the fire has grown too large. A heat-sensitive detector head depends for its operation on the heat transferred to it from the stream of heated gases rising from the fire and spreading out in a layer beneath the ceiling on which the detector head is mounted.

The rate of heat transfer to a detector-head depends both upon the design of the head (its "sensitivity") and upon the temperature and velocity of the stream of hot gases at the point where the detector-head is placed. A test for measuring the sensitivity of a detector head under typical conditions is described in British Standard 3116 : 1960 (1), and acceptable limits of operation are specified for ceilings up to about 15 feet high. Detector-heads must be sited so that wherever a fire may start, the heat transfer to at least one head is sufficient to ensure early operation. The temperature and velocity of the stream of hot gases at the detector head depend upon the size to which the fire has grown, the distance of the detector head from it, and the height, size and characteristics of the ceiling of the building concerned. They may also be affected by other factors such as venting and air-conditioning arrangements.

This report described experimental measurements in actual buildings of different types, in which the conditions in hot-air streams produced by experimental fires have been examined and the results have been used to enumerate the general principles on which the siting of detector-heads may be based.

2. Experimental

The relation between the rate of heat output and time as a fire develops will be different for nearly every fire that occurs, but fires burning steadily with suitable rates of heat output may be used to produce temperature and velocity conditions beneath a ceiling representative of those which would occur at various stages in the development of any fire (2). In the following experiments, methylated spirits was burnt at a steady rate in cylindrical trays with the free surfaces of the liquid maintained at a constant level. Air temperature increases above ambient temperature were measured with fine wire thermocouples, and air velocities were measured with a thermocouple anemometer (3).

Details of the construction of the building and ceiling for which the hot-air streams have been examined, and the experimental arrangements used are given below.

2.1 Corridor

A corridor, closed at one end and open at the other, was constructed with the dimensions shown in Fig.1.

One side was formed by the brick wall of a laboratory; the end wall and part of the ceiling and side wall were of 1/4 inch thick asbestos wood and the remainder of the side wall and the ceiling were clad with $\frac{1}{2}$ in thick sheet fibre glass. The width (A) was adjustable.

Fires were lighted near the closed end and temperature rise and velocity measurements were made at the positions shown in Fig.1. The measurements were made with the fire arrangements shown in Table 1.

Table I - Test arrangements-corridors

Test No.	Corridor width ft	in	Tray diameter ft
1	6	0	1
2	6	0	2
3	11	3	1
4	11	3	2

The free surface of the fuel in the tray was maintained at a constant level by an automatic device which was also used to record the rate of fuel consumption throughout the experiment.

When the rate of fuel consumption had become constant, temperature and velocity measurements were made starting at the station nearest to the fire and working away from it. As half to one hour was required to complete the measurements, the temperature readings nearest to the ceiling at each station were checked before the other measurements were made at each station to see if there had been any general change in the airstream temperature.

2.2 Building with clerestory roof

The dimensions of the building, the roof configuration and the positions of the thermocouples used to measure air temperatures are shown in Fig.2.

In this experiment and those described below, the fuel level was maintained in the tray by "topping-up" from a manually-controlled reservoir; the fires burnt steadily after a few minutes, and measurements were then made.

The fires were positioned either below the apex or below the lower sloping portion of the roof in a plane near an end wall of the building. The central channel of the roof was completely blocked near to the fire on one side but was unobstructed for approximately 100 ft on the other.

Four tests were made with fires arranged as shown in Table II.

Table II - Test arrangements-clerestory roof

Test No.	Tray dia.(ft)	Tray position	Windows
5	2	Vertically below apex (thermocouple No.1)	Closed
6	2	Vertically below lower sloping section (thermocouple No.9)	Closed
7	3	Vertically below apex (thermocouple No.1)	Closed
8	3	Vertically below apex (thermocouple No.1)	Open

The procedure for measuring temperature rise was the same in each test. After the fire had been burning for two minutes, the output from each thermocouple was recorded for thirty seconds. At least two such records from each thermocouple were made during a period of about twenty minutes.

2.3 Building with north-light roof

The experiments were made in a single storey multi-bay building which was 350 ft long x 160 ft wide. The building had brick walls and light steel roof trusses clad with asbestos-cement and wired glass sheets.

The dimensions of the bays, the position of the thermocouples used to measure air temperature rise and the position of the fires, are shown in Figs.3 and 4. Measurements were made with the fire in the positions listed in Table III.

Table III - Test arrangements-North-light roof

Test No.	Tray dia. ft.	Tray position
9	2	Vertically below thermocouple No.1
10	3	Vertically below thermocouple No.1
11	3	Below gutter between bays (a) and (b) and in plane of thermocouple No.1
12	3	Below gutter between bays (a) and (c) in plane of thermocouple No.1
13	3	Below apex at centre of bay (b).

The procedure for measuring temperature rise was the same in each test. After the fire had been burning for five minutes, the output from each thermocouple was recorded.

2.4 Building with large flat ceiling

The dimensions of the building and the positions of the thermocouples used to measure air temperature rise are shown in Fig.5. The fires were positioned vertically below the centre of the ceiling. The sizes of tray used and the distance between the surface of the fuel and the ceiling in each test are shown in Table IV.

Table IV - Test arrangements-flat ceiling

Test No.	Tray diameter - ft	Distance between fuel and ceiling ft	in
14	2	15	9
15	2	24	0
16	2	31	3
17	3	31	3

The procedure for measuring temperature rise was the same in each test. After the fire had been burning for two minutes, the output from each thermocouple was recorded.

2.5 Large building with joisted ceiling

The dimensions of the building and the positions of the thermocouples and the test fire are shown in Fig.6.

Details of the tests are given in Table V

These tests were made in connection with an investigation of smoke detectors and as well as a tray fire of methylated spirits a number of wooden cribs of 1 in square section timber were burnt. Reasonable estimates of the total rate of heat output from these crib fires can be made and it has been assumed that 55 per cent of the total heat output is convected heat.

Table V - Test arrangements-flat ceiling

Test No.	Fire	Estimated convective heat output Kcal/sec	Distance between fuel and ceiling ft.
18	3 ft diam. tray of I.M.S.	60.0	39 ft
19	Wooden crib wt $14\frac{1}{2}$ lbs	38.5	39 ft
20	Wooden crib wt 61 lbs	165	39 ft
21	Wooden crib wt 120 lbs	330	39 ft

3. Results

3.1 Corridor.

The distribution of temperature-rise along the corridor 2 inches below the centre line of the ceiling and the temperature-rise and velocity profiles perpendicular to the ceiling at various distances from the fire are shown in Figs. 7, 8, 9, 10 and 11.

3.2 Building with clerestory roof

The distribution of temperature-rise along the roof 1 ft below the apex (thermocouples Nos 1 - 6) are shown in figs. 12 & 13 and the temperature-rise profiles in two vertical planes for the four experimental arrangements in Figs 14 and 15.

The temperature-rises recorded in the four tests by the two thermocouples under the lower sloping section of the roof (thermocouples Nos 9 and 10) are shown in Table VI.

Table VI - Temperature rise-clerestory roof

Test No.	Distance in direction of ridge from plane of fire. ft	Temperature rise near apex °C	Temperature rise near lower sloping section of roof °C
5	0	24	11
2 ft diam fire beneath apex	37	21	11
6	0		31
2 ft diam fire beneath lower sloping section	37	19	12
7	0	37	23
3 ft dia fire beneath apex	37	29	20
8	0	32	19
3 ft diam fire beneath apex-windows open	37	27	17

3.3 Building with north-light roof

The temperature distributions along the roof of bay (b) 4 in below the apex are shown in Figs.16 and 17. The temperature profiles in two planes for Test No.10 are shown in Fig.18. This type of profile is representative of the results obtained in all the tests in this building.

The temperature rise 4 in below the apex in bays (a) and (c), each side of the bay in which the test fire was placed, were measured with thermocouples 11 and 12 in Tests 9 and 10 and are given in Table VII. The temperature rises halfway down one slope of the roof of bay (b) measured with thermocouples 11 and 12 in Tests 11, 12 and 13 are also shown in Table VII.

Table VII - Temperature rise-North-light roof

Test No.	Temperature rise °C recorded by thermocouple No	
	11	12
9	3.5	0
10	4.3	2.2
11	3.5	3.0
12	2.3	3.2
13	2.8	1.5

3.4 Building with large flat ceiling

Temperature distributions along the length of the building 2 in below the ceiling and a representative temperature profile are shown in Fig. 19 and 20.

3.5 Tall building with joisted ceiling

Temperature distributions along the length of the building 11 in below the ceiling are shown in Fig.21.

4. Determination of convective heat output from test fires

Rates of total heat output were calculated by multiplying the evaporation rates by the calorific value of the fuel used (7,000 cal/gm for industrial methylated spirits and 4,400 cal/gm for the wood) The evaporation rates from the trays burning in the corridors (Tests 1-4) were higher than those in the other tests, presumably because of the higher heat transfer to the fuel from the smaller structure.

The heat radiated from the fires in which trays of fuel were used (Tests 1-15) was calculated from measurements of the radiation from the fires in experiments described in Appendix.1.

The heat output rates are summarised in Table VIII.

Table VIII Heat output rates from test fires

Test No.	Tray dia. ft	Average evaporation rate cc/s	Total heat output K.cal/s	Convective heat output K cal/s
1 - 4	1	1.4	7.65	5.35
	2	6.75	36.8	25.0
5 - 18	½	0.213	1.16	0.87
and experiments with flat ceiling reported elsewhere (2)	1	1.17	6.39	4.48
	2	5.69	31.1	21.2
	3	16.4	89.6	60.0

5. Discussion of results

It is convenient to discuss the flow of hot gases set up in the buildings by the experimental fires in two parts; firstly considering the columns of gas rising from the trays to the ceilings and secondly the layers spreading beneath the ceilings.

5.1 The rising column.

Conditions in a column of gas rising freely from a circular heat source have been discussed by a number of workers (4) (5) (6). The gases rise in the shape of an inverted cone entraining air as they rise and the rise in temperature in a horizontal plane in the stream shows a maximum on the axis and tends to zero at the periphery of the cone. Yih (5) using a bunsen burner as a heat source, found that the temperature distributions could be expressed by the formula.

$$\left\{\frac{-h^5}{\rho G^2}\right\}^{1/3} \Delta\gamma = 11e^{-\frac{1}{2}\left(\frac{r}{\cdot 084h}\right)^2} \qquad (1)$$

where
- ρ - density of hot gases
- h - vertical distance from the point source
- $\Delta\gamma$ - "specific weight" $= g(\rho - \rho_o)$
- r - radial distance

and $G = -\int_0^{\infty} 2\pi r u \Delta\gamma \, dr$

where u - vertical velocity

Transforming Equation (1) to terms which could be measured in the test fires we get for the maximum temperature rise (θ_c) on the axis of the plume.

$$\theta c = 40(To + \theta c)^{2/3} . Q^{2/3} . h^{-5/3} \qquad (2)$$

Since the test fires were not point sources a correction based on the angle of spread of the plume suggested by G.I.Taylor (4) may be introduced by substituting h' for h, where

$$h' = h + 1.3\ d$$

$$\text{giving} \quad \theta c = 40\ (To + \theta c)^{2/3} . Q^{2/3} (h + 1.3d)^{-5/3} \qquad (3)$$

where
- To - absolute ambient temperature
- Q - convected heat output from fire
- h - vertical distance from the fire
- d - diameter of the fire

When the rising plume from a fire reaches the ceiling of a building it will spread and form a layer of hot gas under the ceiling. The thickness of this layer D, will depend on the type of roof construction, and any ventilation losses that may occur. In calculating the temperature rise near the ceiling the height in which turbulent mixing will take place should therefore be (h - D) and the term used in Equation (3) (h + 1.3d -D).

Estimates of D were made from the test results and in Fig.22 the temperature rises on the axis of the fire beneath the ceiling are plotted against a similar function to the right hand side of Equation 3. Included in Fig.22 are the results reported previously (2) on a ceiling, 20 ft x 24 ft with unrestricted edges.

The results of all the tests can be correlated in the following way -

$$\theta c = 38\ Q^{2/3}(To + \theta c)^{2/3}(h + 1.3d)^{-5/3} \qquad (4)$$

$$\text{and} \quad \theta c = 23.5\ Q^{2/3}(To+\theta c)^{2/3}(h + 1.3d - D)^{-5/3} \qquad (5)$$

where h - distance from fire to ceiling (cm)

d - diameter of fire (cm)

D - depth of hot layer beneath ceiling (cm)

To - absolute ambient temperature (assumed 280°C)

Q - convected heat output cal/sec

θc - temperature on axis of plume °C

5.2 Hot gases spreading beneath ceilings

When the hot gases from the fire reach the ceiling they spread out and form a moving layer of gas which is less dense than the air in the building. This layer can be cooled in travelling along the ceiling by heat losses to the ceiling and by turbulent mixing with the cooler air beneath the layer. If the energy of turbulence is insufficient to lower the light hot gases and raise the heavier cool air then this turbulent mixing will be damped out. The value of the ratio between the work done against gravity and the work done by the turbulent stresses is a measure of the degree of turbulent mixing. This ratio is known as the Richardson number = $\frac{g.\Delta\rho.D}{\rho.u^2}$

when $\Delta\rho$ - density difference between the hot stream and the ambient air

D - depth of the hot layer

ρ - density of the hot gases

u - velocity of the hot gas stream.

The smaller the Richardson number the better the turbulent mixing and it has been shown (7) that turbulent mixing ceases when Richardson's number exceeds a critical value of about 0.8.

Values of the Richardson number have been calculated for those tests in which velocity measurements were made and are given in Table IX together with values calculated for results reported elsewhere (2).

Table IX Values of Richardson number of gas stream beneath ceiling at 5 fire diameters from the axis of the plume

Test No.	Richardson number at 5 diameters
Tests on 20' x 24' ceiling (2)	0.85 - 12.7
1	2.9
2	1.5
4	2.3
10	9.8

These results suggest that there will be little if any cooling of the gases near the ceiling due to turbulent mixing and if the heat losses to the ceiling are low, the temperature in the stream some distance from the fire should be similar to the 'mixed' temperature of the gases in the rising plume. These should also be little further reduction in temperature as the hot gases spread throughout the building.

The mixed temperature of the gases in the rising plume at the ceiling can be calculated and in the same nomenclature as used in Equation (2) is

$$\theta m = 23.7 \, (To + \theta c)^{2/3} \, Q^{2/3} \, h^{-5/3} \quad (6)$$

$$\text{or} \quad \theta m \quad 0.6 \, \theta c \quad (7)$$

The measured temperature rises beneath the ceiling 40 feet from the axis of the fire in the tests have been plotted against the measured temperature rise directly above the fire in Fig.23. It can be seen that this agrees well with the line $\theta m = 0.6 \, \theta c$ where θc was calculated from Equation (5). It is evident, therefore, that there is little cooling of the hot gas layer beneath the ceiling by turbulent mixing in any of the tests and that the heat losses to the ceiling can also be ignored to a first approximation.

5.3. General comments

In tests No.9 and 10 in which the test fires were near the end wall of a bay of the building with a north - light roof, the axis of the plume of hot gases was not vertical and the maximum temperatures were recorded some distance from the vertical axis (Fig.17). This was probably due to a zone of stagnant air near to the end wall of the building. The entrainment of air into the rising plume was also restricted under these conditions and this accounts for the rather higher temperatures recorded above the fire in Test No.10 than in Test No.13 where the fire was in the centre of the bay (Fig.17).

In tests 11 and 12 where the test fire was beneath the gutter between adjacent bays, the rising plume of hot gas split between two bays and the temperature-rises at the apex were less than the rise measured with a fire of the same size beneath the apex.

In test 6 in which the test fire was beneath the lower sloping section of the roof with a clerestory above, the temperature rise at the apex of the clerestory was 19°C, whereas with the same size fire beneath the apex it was 24.5°C. There was, however, little difference in the temperature of the hot gas stream some distance from the axis.

5. Application of results to siting of detectors

When considering the sensitivity and spacing of the detectors of any installation it is necessary to decide what size of fire must be detected. The lower limit to the size will be determined usually by the need to avoid false alarms and the upper limit by the need to give a warning before the fire has grown large enough to spread so rapidly that it cannot be contained by the fire-fighting facilities available.

Using the data given in this report it is possible to estimate the size of fire that would be detected under different conditions by detectors having sensitivities within the range given in BS 3116. It is first necessary to calculate the temperature rise of the airstream necessary to operate detectors corresponding to the upper and lower limits of BS 3116. If it is assumed that the temperature of the air rises linearly with time then these are the products of the rate of rise of temperature and the operating times and are shown graphically in Fig.24

By substituting these values of temperature in Equations 4 and 7 it is possible to calculate the rates of heat output necessary to operate detectors at the upper and lower limits of BS 3116 in buildings of different ceiling height both when the detector is directly above the fire and when it is more than about 20 ft from the axis of the fire.

This information is given in Table X and is shown graphically in Figs.25 and 26.

Table X Minimum sizes of fire necessary to operate detectors under different conditions

Ceiling height ft	Sensitivity*	Convective heat output from fire to operate detectors Kcal/sec			
		Detectors directly above fire		Detectors > 20ft from axis of fire	
		5°C/min	25°C/min	5°C/min	25°C/min
10	high	3.9	1.9	7.8	3.9
	low	13.1	26.2	27.4	48.0
20	high	21.9	10.5	44.2	21.9
	low	80.8	148.2	154.5	268.3
30	high	61.6	29.3	125	61.6
	low	227	416	433	745

* high - most sensitive possible within the limits of BS.3116
low - least sensitive possible within the limits of BS.3116

Note In calculating the figures in Table X the following values of 'd' were assumed -
10 ft ceiling height - d = 30 cms
20 ft ceiling height - d = 60 cms
30 ft ceiling height - d = 90 cms

For comparison the rates of convected heat output from trays of different diameter burning methylated spirits are

1 ft diameter - 5.4 Kcal/sec
2 ft diameter -21.2 "
3 ft diameter -60 Kcal/sec.

It can be seen that the minimum size of fire which can be detected is very dependent on the height of the building and the sensitivity of the detector. It is in fact much more dependent on these two factors than on the spacing of the detectors. Thus in a building such as a North roof light type, 20 ft high, the most sensitive detector directly above the fire would detect a rapidly developing fire with a rate of heat output of about 10 Kcal/sec whereas the fire would have to have a heat output of about 150 Kcal/sec to be detected by the least sensitive detector directly above it. With only one sensitive detector in the bay, even if the fire started a long distance away in the same bay, it would be detected when it had reached a rate of heat output of about 22 Kcal/sec.

The most which can be achieved by mounting detectors close together is a reduction by a factor of about two in the size of fire which can be detected. This compares with a reduction by a factor of about 4 - 15 which can be achieved by increasing the sensitivity within the limits of BS 3116.

Conclusions

Temperature and velocity measurements in buildings with various roof constructions with steadily burning test fires have given a clear indication of the most important factors in the siting of heat sensitive detectors.

The temperature near the ceiling directly above a fire of a known heat output can be calculated and it has been shown that the temperature near the ceiling falls to approximately 60 per cent of this value within 10 - 20 ft and then remains sensibly constant.

The efficiency of a detector system can be judged by the minimum size of fire which can be detected by the system and in these terms we may judge the effect of the various factors involved.

(1) Height of ceiling

The minimum size of fire which can be detected by a detector depends on the height, h, to the power $5/2$. Thus a given detector under a ceiling 20 ft high will operate when the rate of heat output from the fire is about $5\frac{1}{2}$ times that necessary to operate the same detector beneath a 10 ft ceiling. For a 30 ft high ceiling, this factor increases to approximately 15 - 16.

(2) Sensitivity

A wide range of sensitivity is possible within the limits of BS 3116 and the effect of the sensitivity depends on the rate of development of the fire, being greatest for rapidly developing fires.

If the temperature of the gases near the detector rises at 5°C/min the least sensitive detector will require a fire of about $3\frac{1}{2}$ times the rate of heat output required to operate the most sensitive detector. If the temperature of the gases rises at 25°C/min, the factor of $3\frac{1}{2}$ is increased to 14.

(3) Spacing

By spacing detectors very close together the maximum improvement which can be achieved is that a fire with half the rate of heat output can be detected compared with, say, one detector in a building with a flat ceiling, or one detector in each bay of a building with a North roof light.

The above considerations indicate the most important factors to be considered when installing a heat-sensitive fire detection system in a building. The experimental work has assumed an uninterrupted flow of the hot gases in the heated layer beneath the ceiling, except in so far as the type of ceiling and the outer dimensions of the building are concerned, that is, it has not taken into account any possible variation of behaviour due to roof ventilators, open stair wells, obstructions etc. While these may modify the flow pattern, however, it is unlikely that they will affect materially the main conclusion of the great importance of sensitivity, particularly for ceilings above average height,

Acknowledgement

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Appendix I

Measurements of radiation from trays of burning methylated spirits.

The heat radiated by the flames from methylated spirits burning in circular trays was estimated from measurements made with radiometers supported at intervals round semi-circular frames erected in a vertical plane (fig 27). The radiometers were pointed towards the centre of the semi-circular arc.

The total radiated heat was estimated from the expression

$$I = 2\pi r^2 \int_0^{\pi} i . \sin \theta . d\theta$$

where I is the total radiated heat (cal/s)
and i is the intensity through an element of area subtending an angle d θ, of the surface of a sphere obtained by rotating the arc (cal/cm²/s)

The fraction of the total heat output radiated from trays having diameters between 6 in and 3 ft is shown in fig (27).

References.

1. British Standard 3116 : 1959. Heat Sensitive Detectors for Automatic Fire Alarm systems in Buildings.

2. PICKARD,R.W, HIRD,D and NASH,P. The Thermal Testing of Heat-Sensitive Fire Detectors, F.R.Note No. 247/1957.

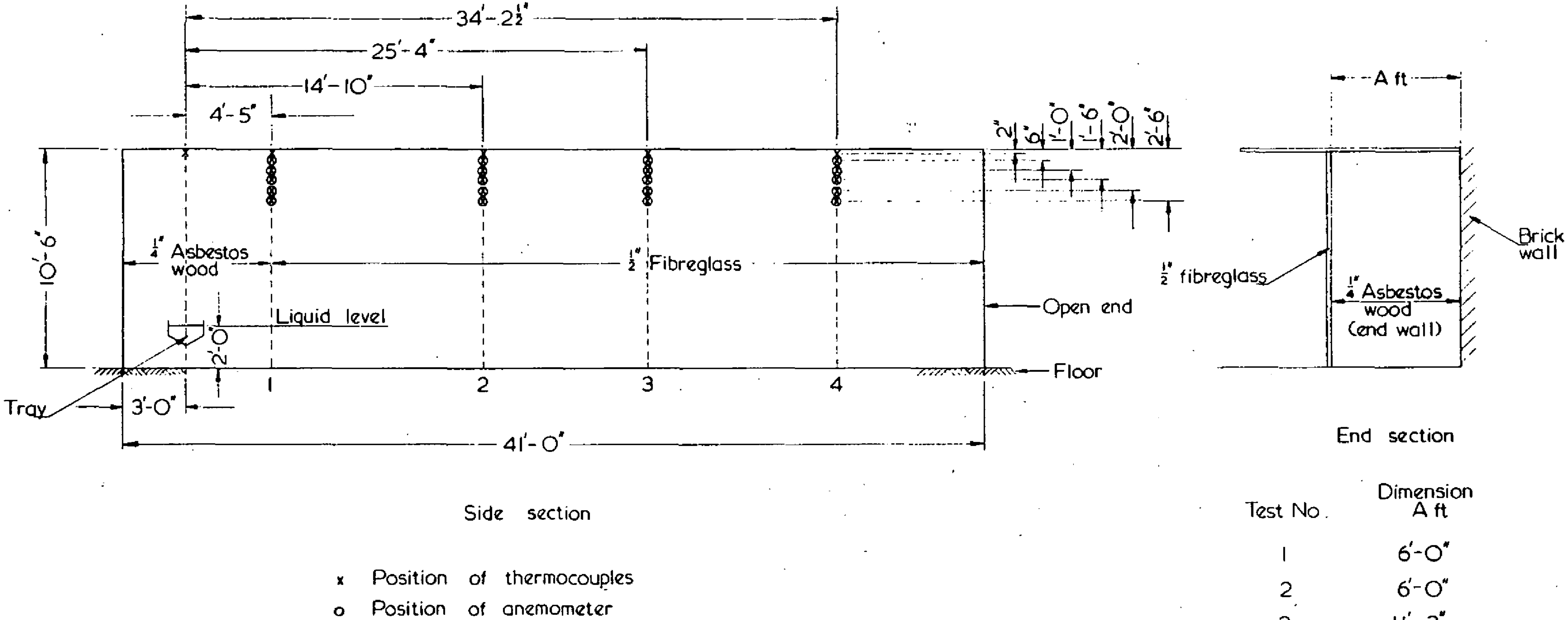
3. BENSEMAN R.F. and HART H.R. A Thermocouple Anemometer. J.Scientific Instruments. April 1955, Vol. 32 No.4

4. TAYLOR G.I. The dispersal of fog from airfield runways. ed. Walker E.G, and Fox D.A. Ministry of Supply, London 1946.

5. YIH C.S. Free convection due to a point source of heat. Proc 1st U.S. Nat. Congr. Appl. Mech, 1952, 941 - 7.

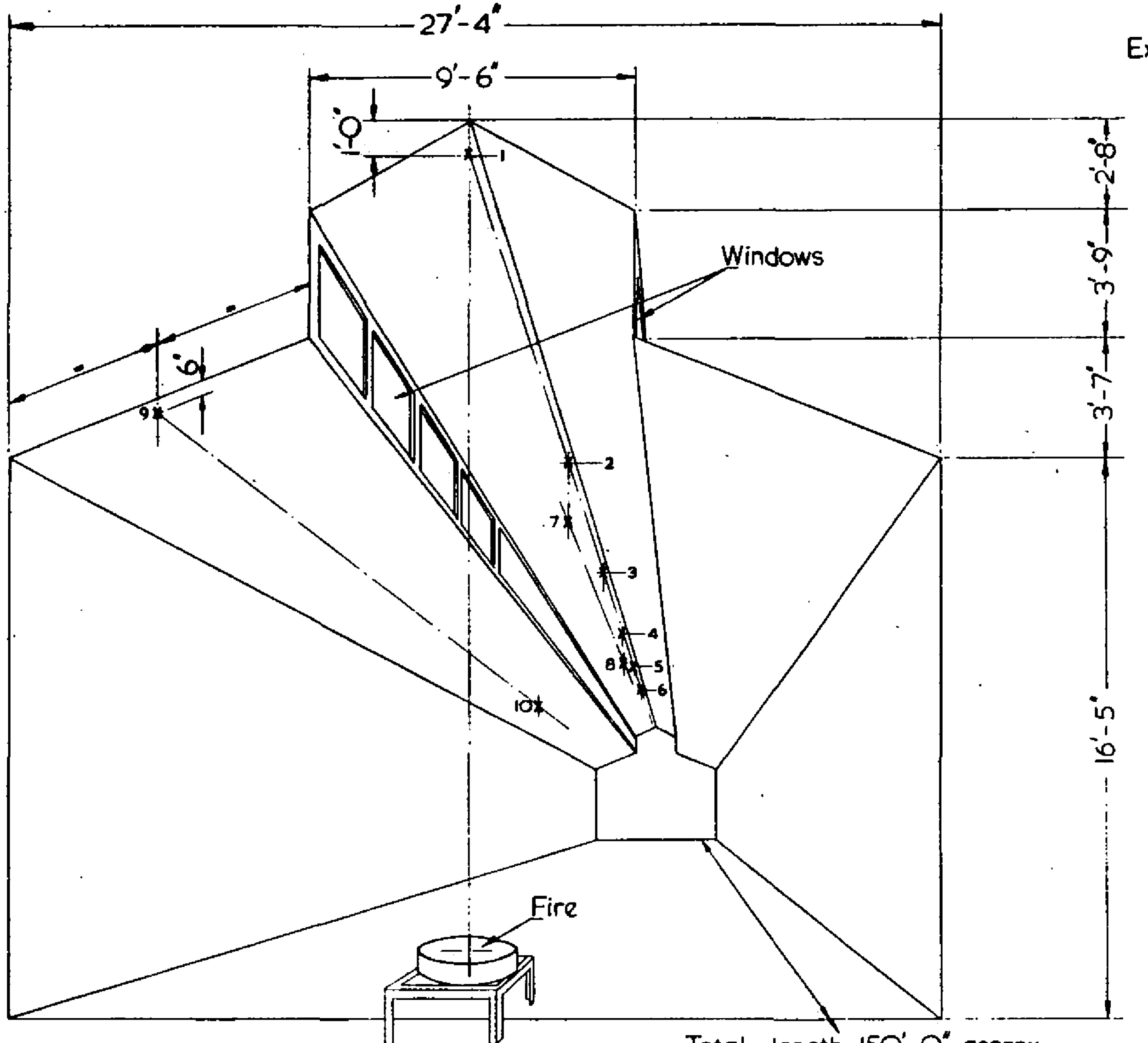
6. YOKOI S. Study of the prevention of fire spread caused by hot upward current. Report of Building Research Institute of Japan No.34.

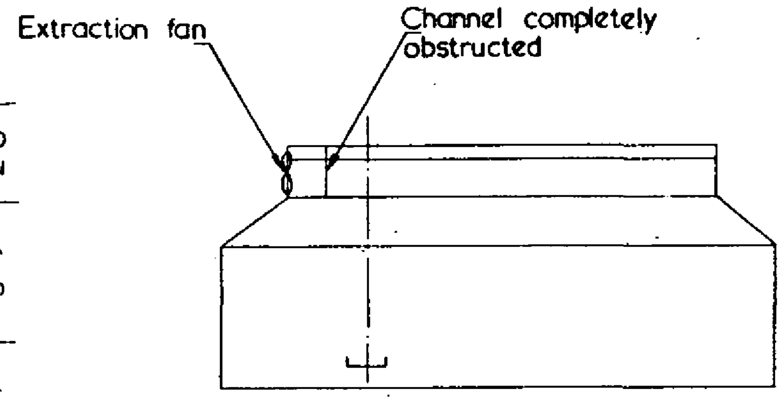
7. BAKKE P. On the dispension of methane roof layers by ventilation. 10th Int.Conf.of Directors of Safety in Mines Research Pittsburgh U.S.A. 1959.



Test No.	Dimension A ft
1	6'-0"
2	6'-0"
3	11'-3"
4	11'-3"

FIG. 1. DIMENSIONS OF CORRIDOR





Thermocouple positions

No	Position
1	In plane of fire
2	12'-4" from 1
3	24'-8" from 1
4	37'-2" from 1
5	49'-6" from 1
6	62'-4" from 1
7	3'-4" below 2
8	3'-4" below 4
9	In plane of 1
10	In plane of 4

FIG. 2. DIMENSIONS OF CLERESTORY ROOFED BUILDING

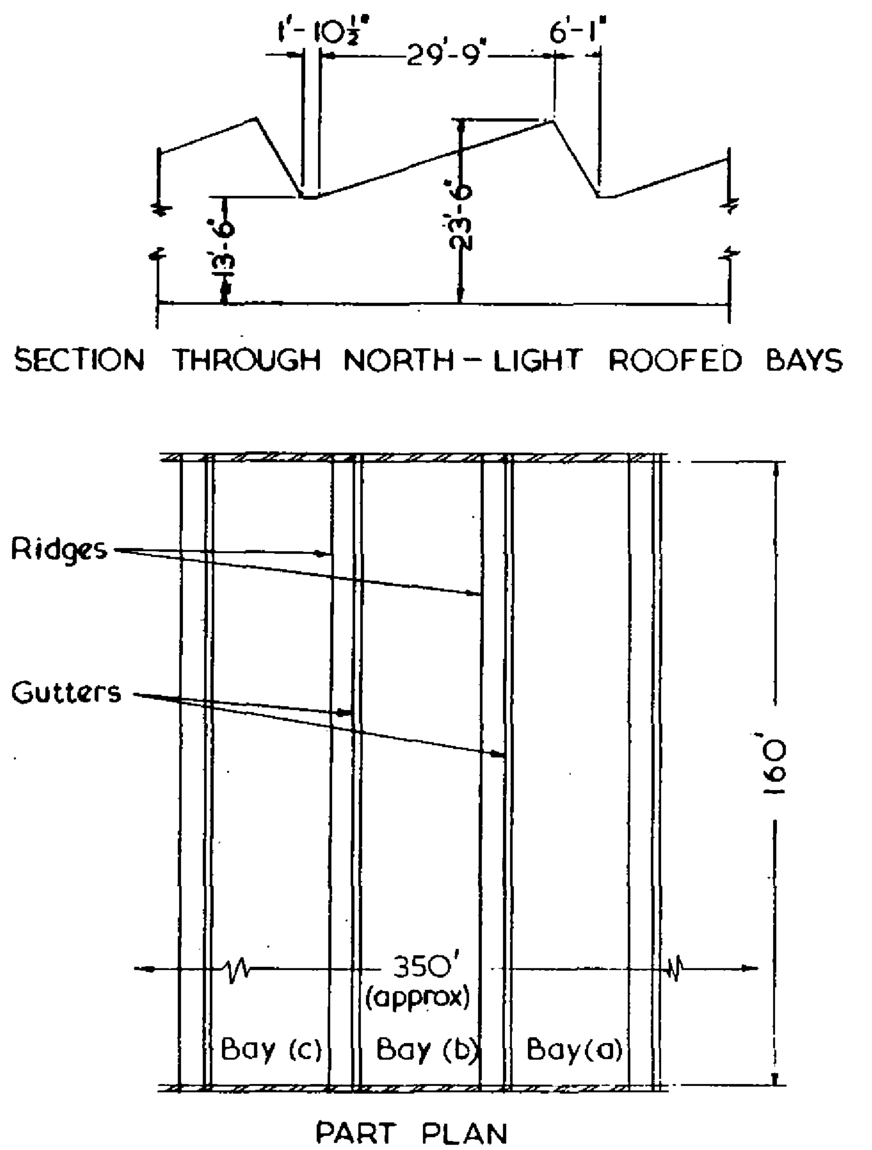


FIG. 3. DIMENSIONS OF BUILDING WITH NORTH-LIGHT ROOF

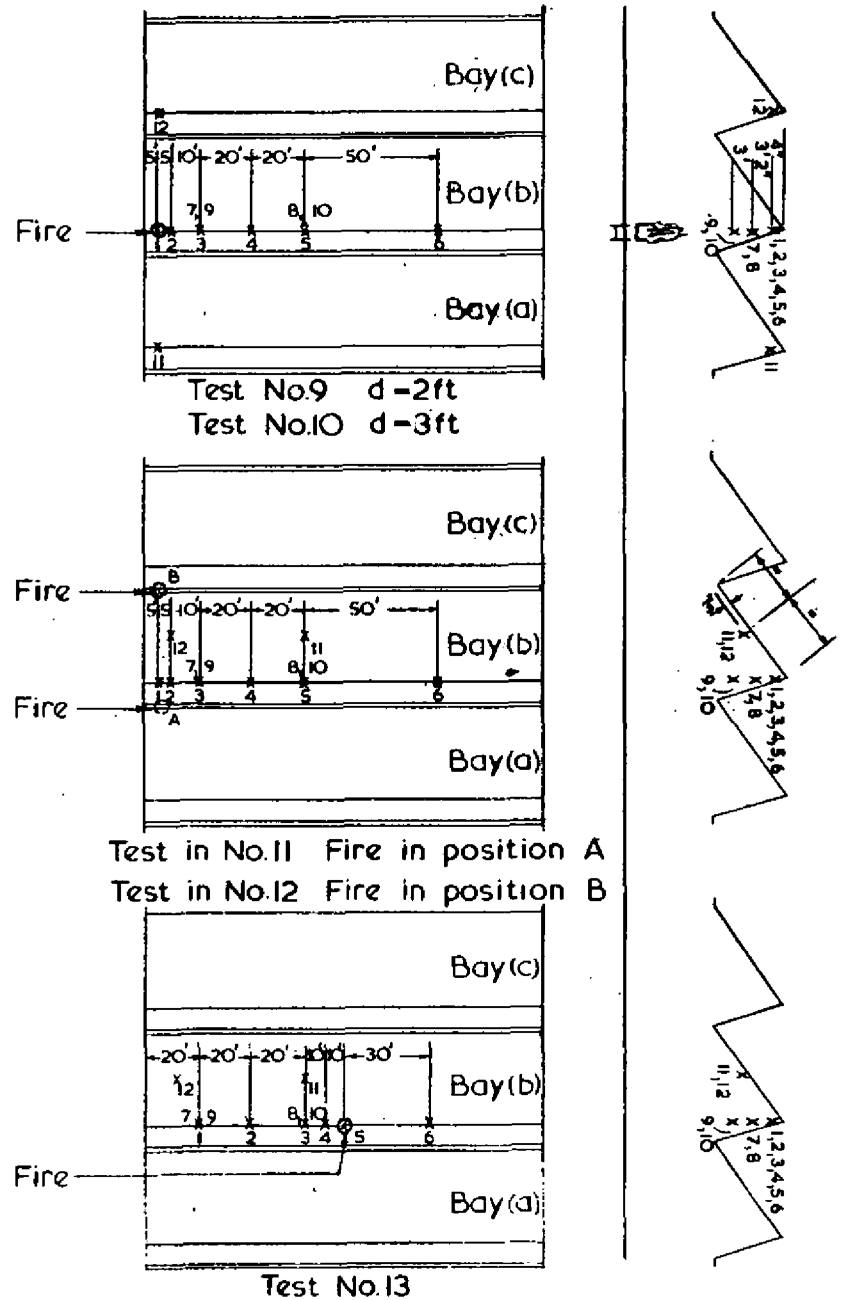
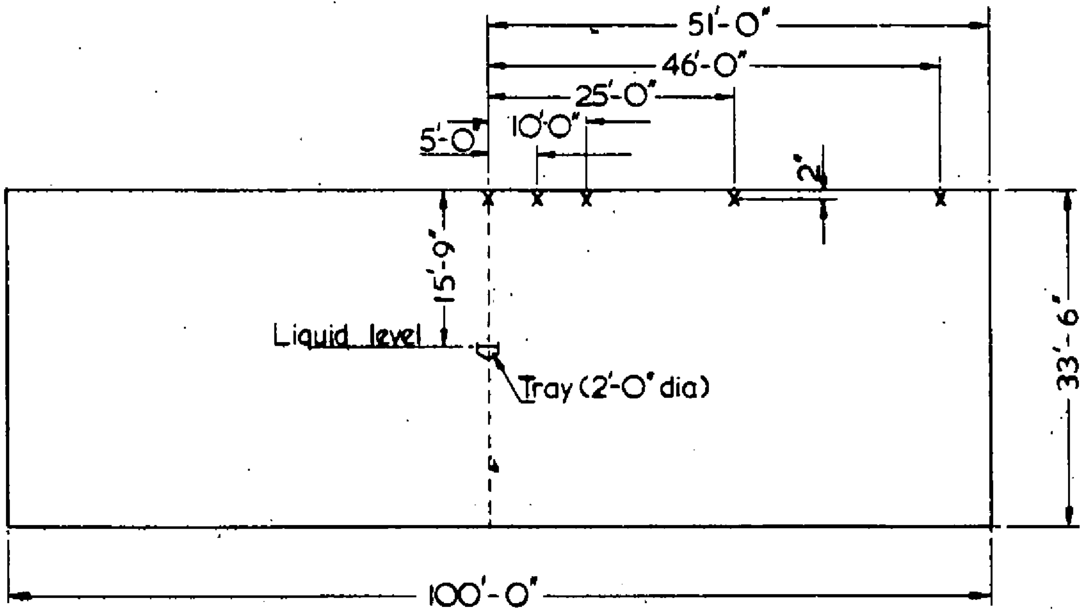
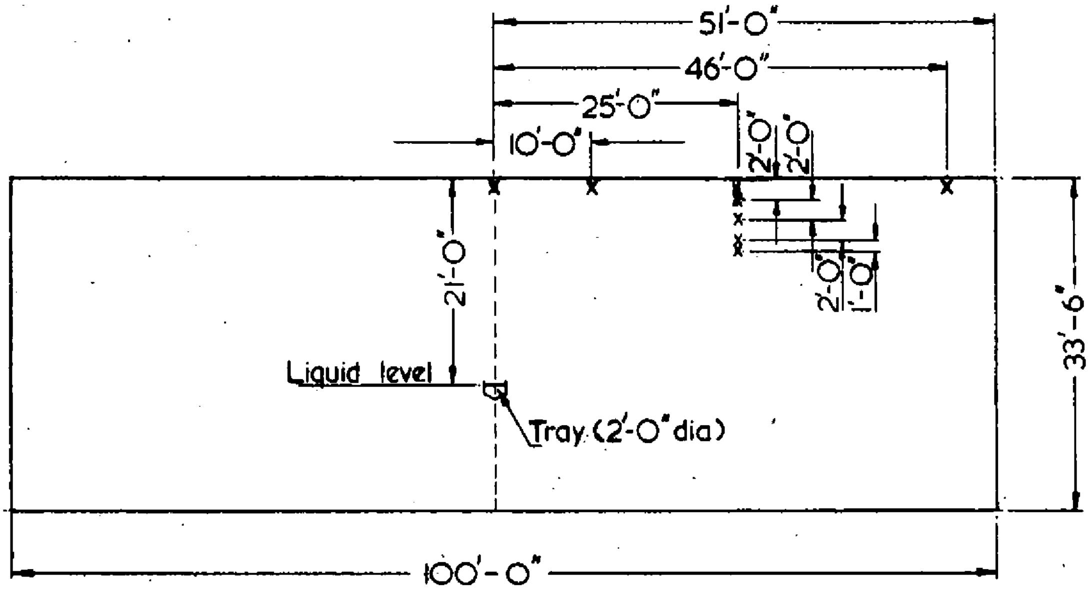


FIG. 4. POSITION OF FIRES AND THERMOCOUPLES IN BUILDING WITH NORTH LIGHT ROOF



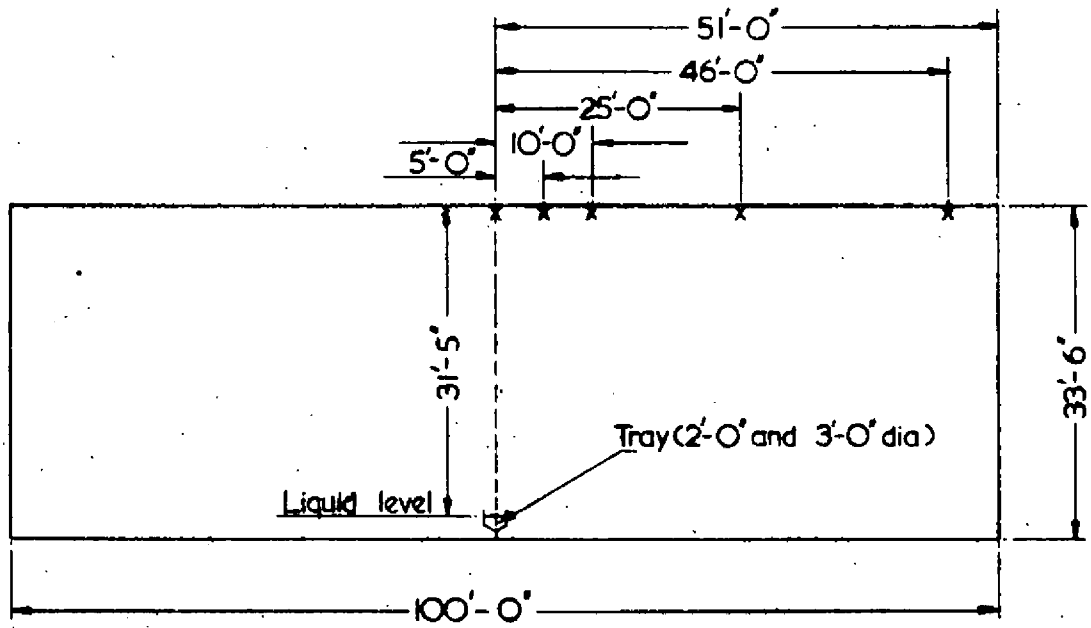
x–Position of thermocouples

Test 14



x–Position of thermocouples

Test 15



x–Position of thermocouples

Tests 16 and 17

FIG. 5. POSITION OF FIRES AND THERMOCOUPLES IN BUILDING WITH LARGE FLAT CEILING

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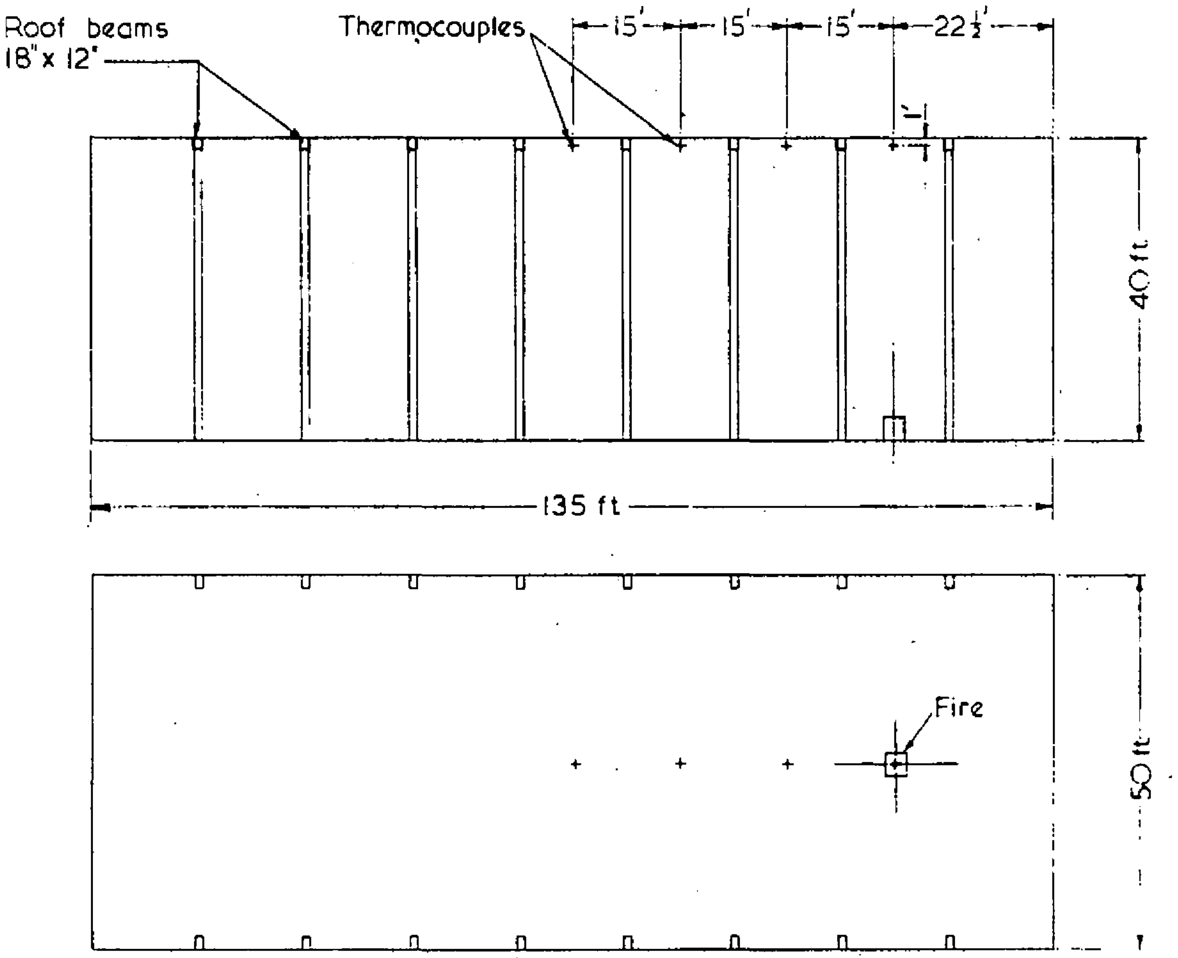
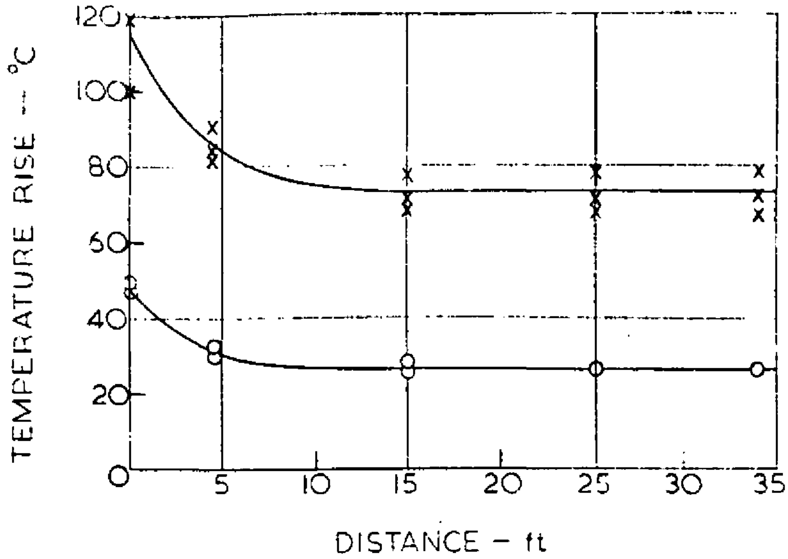


FIG. 6. POSITION OF FIRES AND THERMOCOUPLES. BUILDING WITH JOISTED CEILING

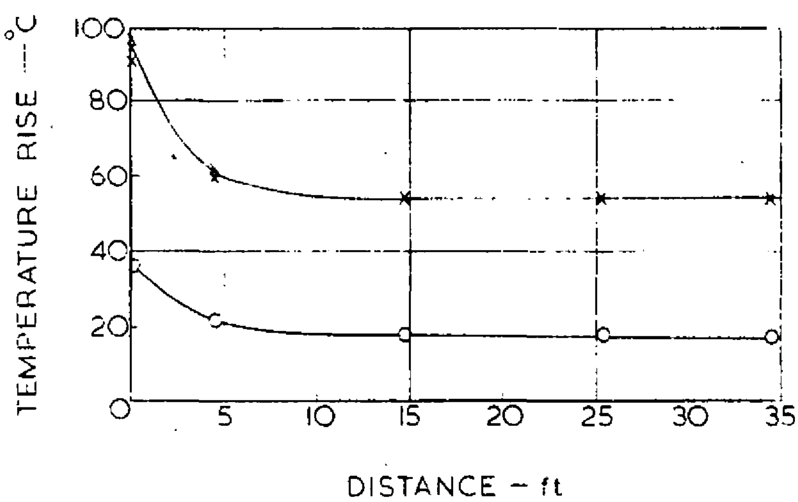


Distance from fire to ceiling – 8 ft 6 in

Test No. 1. —o— 1 ft dia tray fire (convected heat output 5·35 Kcal/s)

Test No. 2 —×— 2 ft dia tray fire (convected heat output 25·0 Kcal/s)

FIG. 7. TEMPERATURE RISE 2in BELOW CEILING, OF 6ft WIDE CORRIDOR (TESTS No 1 & 2)



Distance from fire to ceiling — 8 ft 6 in

Test No. 3 —o— 1 ft dia. tray fire (convected heat output 5·35 Kcal/s)

Test No 4 —×— 2 ft dia. tray fire (convected heat output 25·0 Kcal/s)

FIG. 8. TEMPERATURE RISE 2in. BELOW CEILING, OF 11ft 3in. WIDE CORRIDOR (TESTS No 3 & 4)

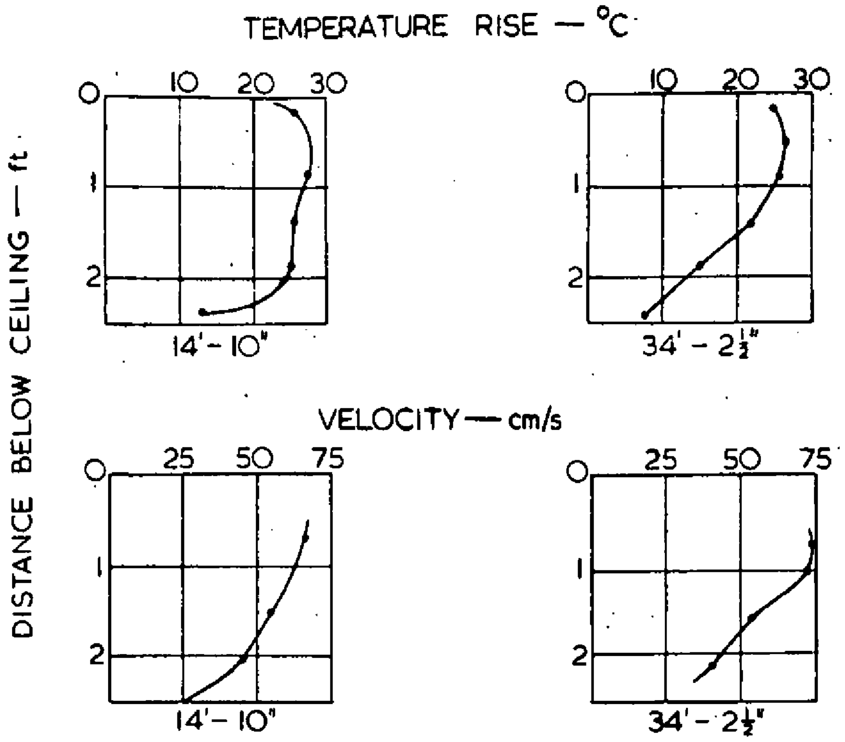


FIG. 9. TEMPERATURE AND VELOCITY PROFILES IN 6ft WIDE CORRIDOR WITH 1ft DIAMETER FIRE (TEST No.1)

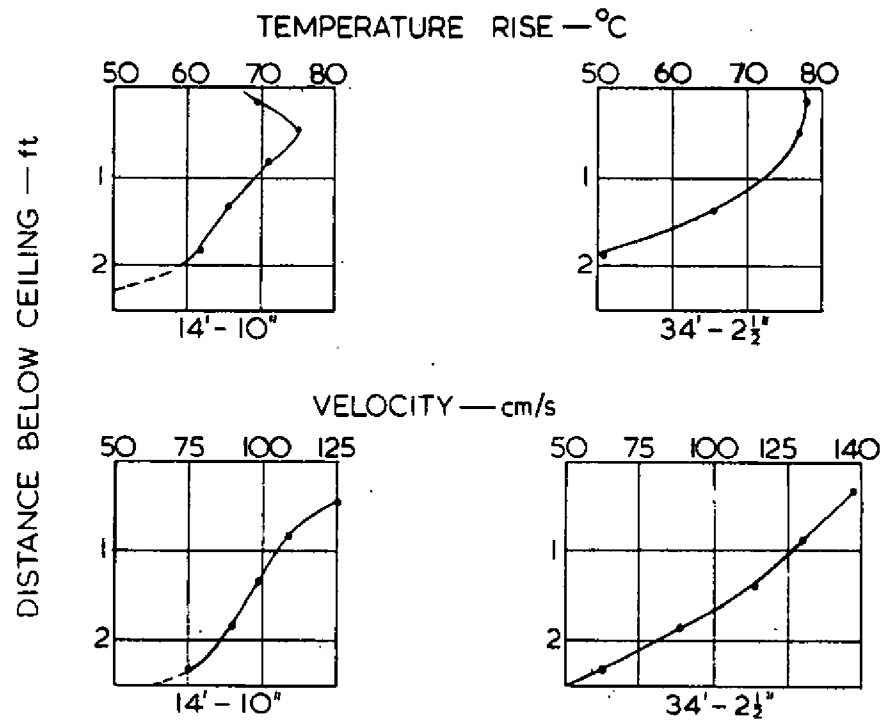


FIG. 10. TEMPERATURE AND VELOCITY PROFILES IN 6ft WIDE CORRIDOR WITH 2ft DIAMETER FIRE (TEST No.2)

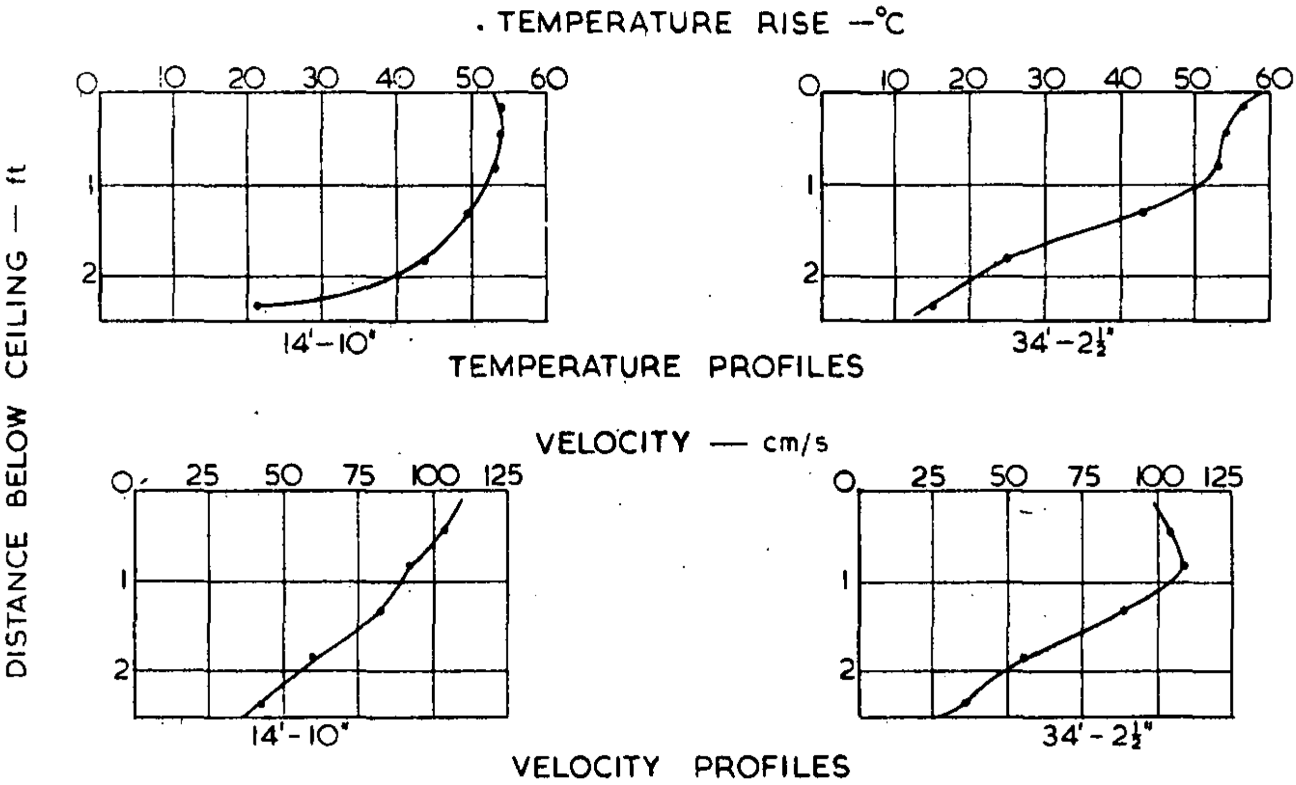
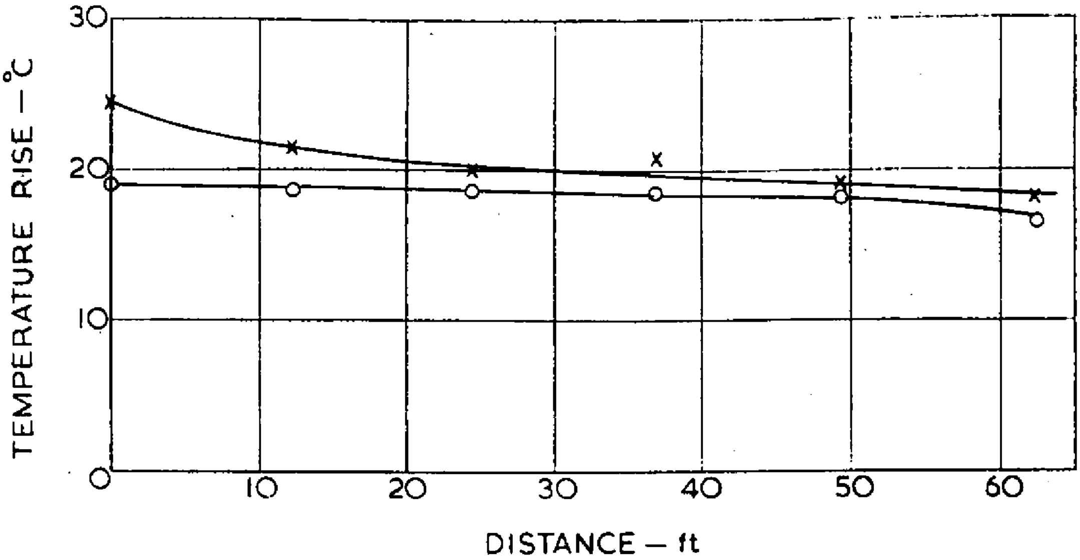


FIG. 11. TEMPERATURE AND VELOCITY PROFILES IN 11 ft 3 in. WIDE CORRIDORS WITH 2 ft DIAMETER FIRE (TEST No. 4.)

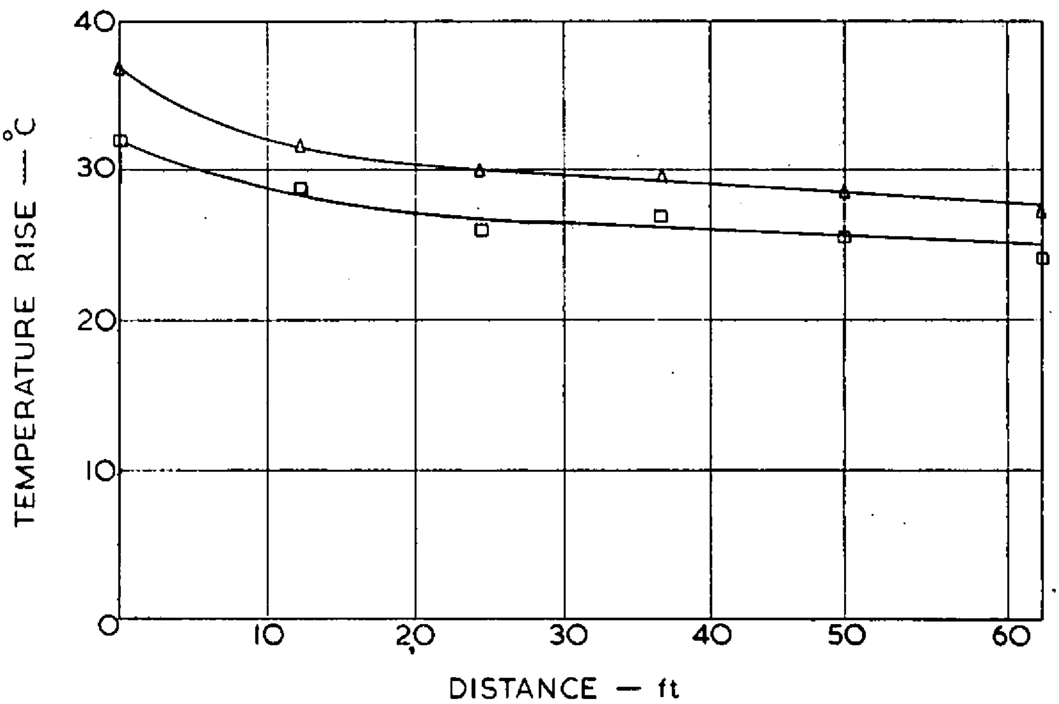


Vertical distance from fire to measuring point — 23 ft 4 in.

Test No.5 —×—×— 2 ft dia. fire (convected heat output = 21·2 Kcal/s) beneath apex

Test No.6 —o—o— 2 ft dia. fire (convected heat output 21·2 Kcal/s) beneath lower sloping section

FIG. 12. TEMPERATURE RISE 1 ft BELOW APEX IN CLERESTORY TYPE BUILDING. TESTS No. 5 & 6



Vertical distance from fire to measuring point — 23 ft 4 in.

Test No 7 —△—△— 3 ft dia. fire (convected heat output = 60·0 Kcal/s) beneath apex with windows closed

Test No.8 —□—□— 3 ft dia. fire (convected heat output = 60·0 Kcal/s) beneath apex with windows open

FIG. 13. TEMPERATURE RISE 1 ft BELOW APEX IN CLERESTORY TYPE BUILDING TESTS No. 7 & 8

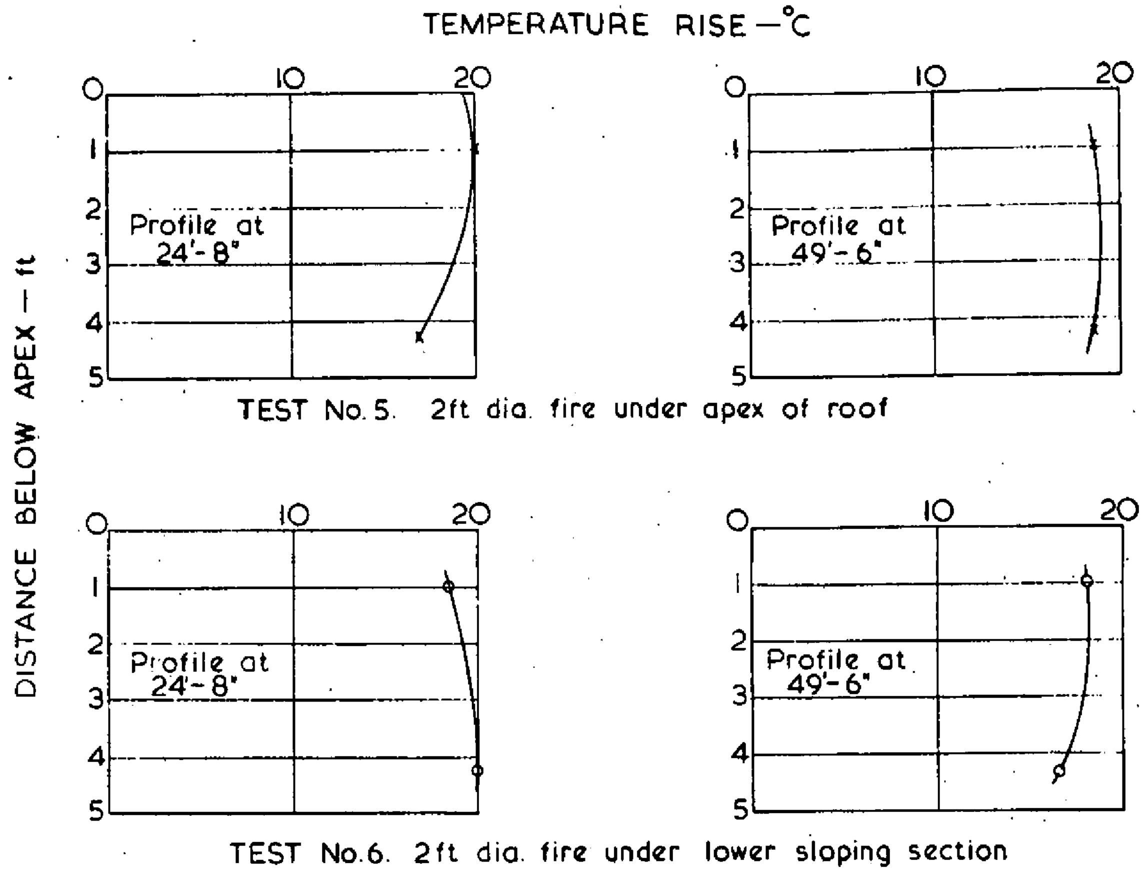


FIG. 14. TEMPERATURE PROFILES IN TESTS No. 5 & 6

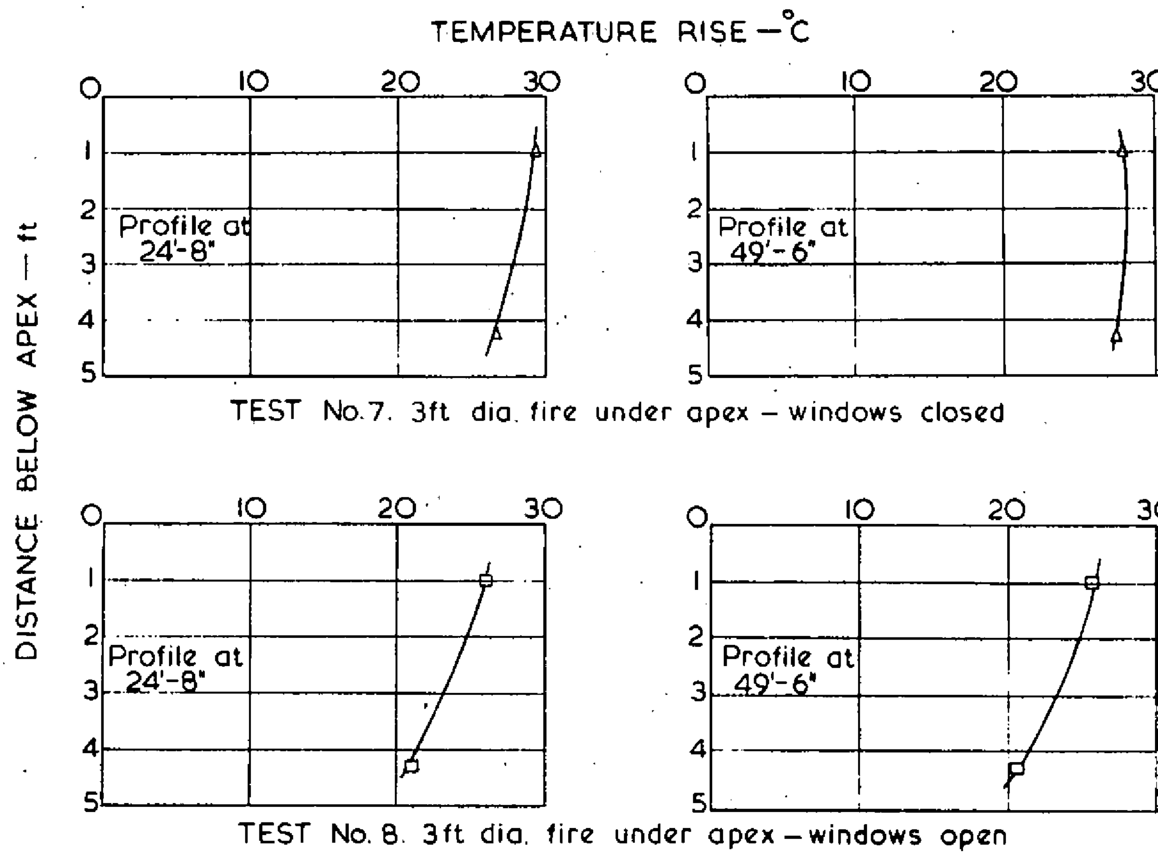


FIG. 15. TEMPERATURE PROFILES IN TESTS No. 7 & 8

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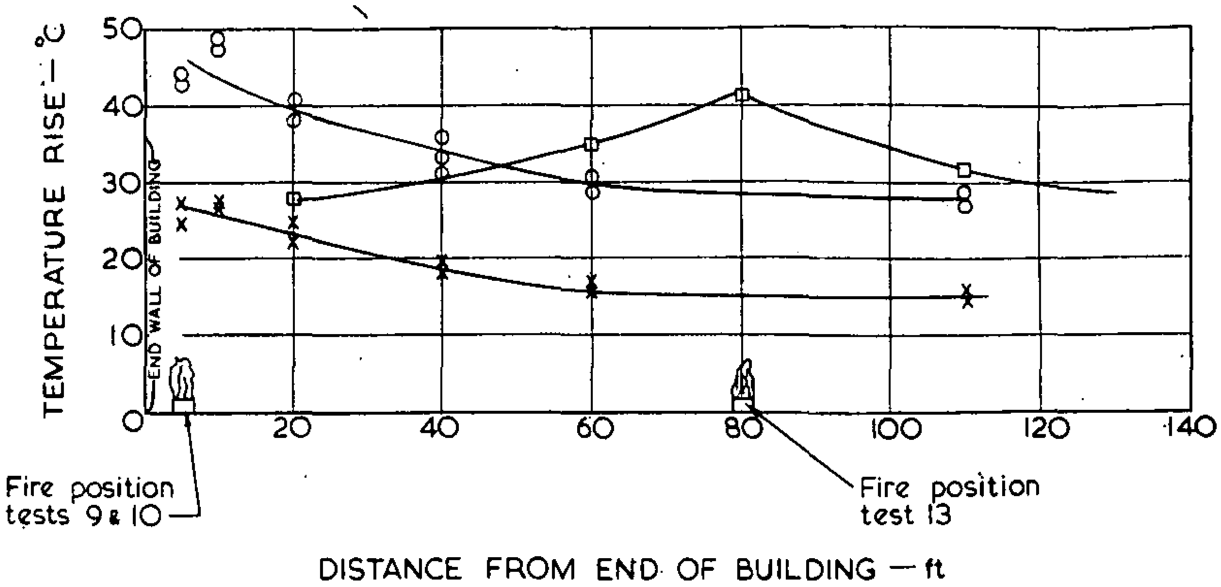
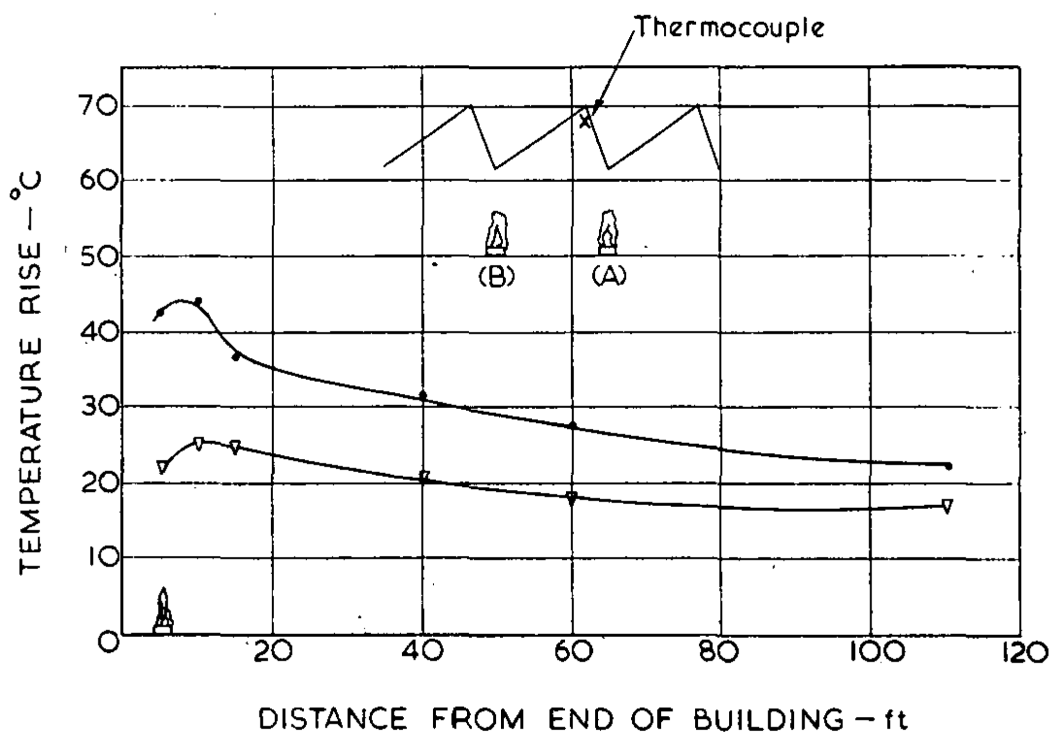


Test No.9 —×— 2 ft dia. fire (convected heat output 21·2 Kcal/s)
Test No.10 —○— 3 ft dia. fire (convected heat output 60·0 Kcal/s)
Test No.13 —□— 3 ft dia. fire convected heat output 60·0 Kcal/s)

FIG. 16. TEMPERATURE RISE 4in. BELOW APEX OF BUILDING WITH NORTH-LIGHT ROOF – FIRE BELOW APEX TESTS 9, 10 & 13



Test No.11 —•— 3 ft dia. fire (convected heat output 60·0 Kcal/s) Fire (A)
Test No.12 —▽— 3 ft dia. fire (convected heat output 60·0 Kcal/s) Fire (B)

FIG. 17. TEMPERATURE RISE 4in BELOW APEX OF BUILDING WITH NORTH-LIGHT ROOF – FIRE BELOW GUTTER TESTS No. 11 & 12

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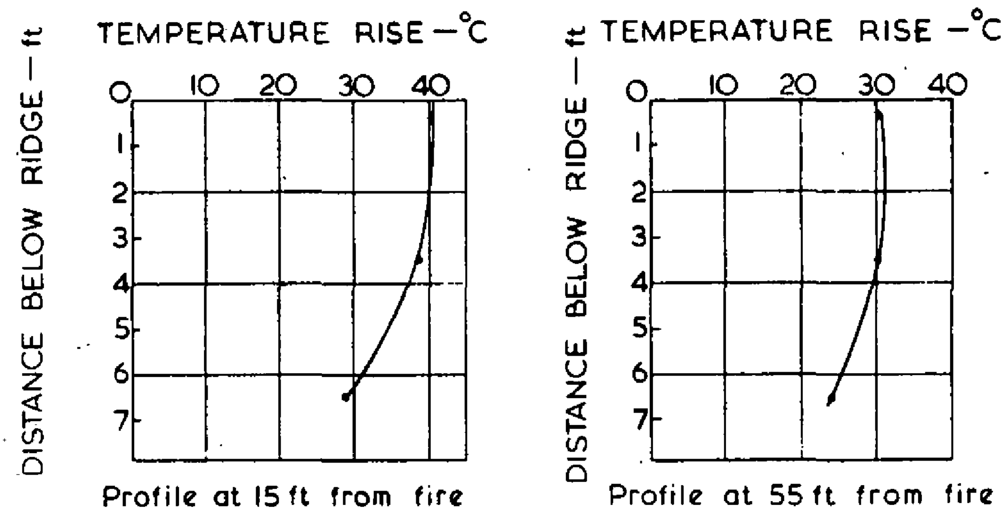

FIG. 18. TEMPERATURE RISE PROFILES. TEST No. 10.

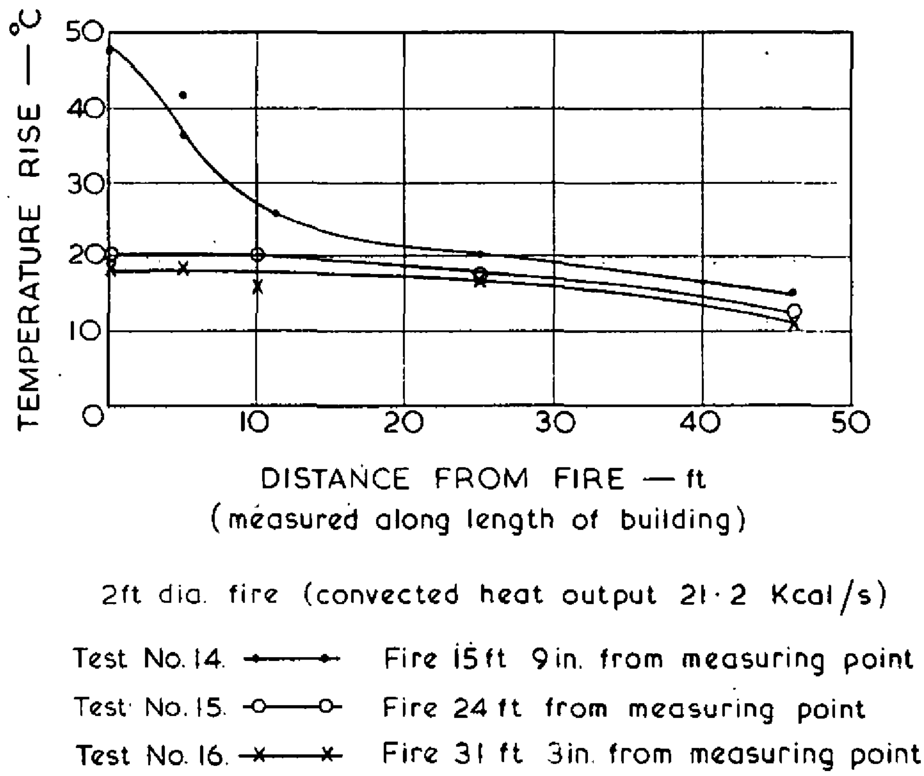

FIG. 19. TEMPERATURE RISE 2in. BELOW FLAT CEILING OF LARGE BUILDING. TESTS 14, 15, 16

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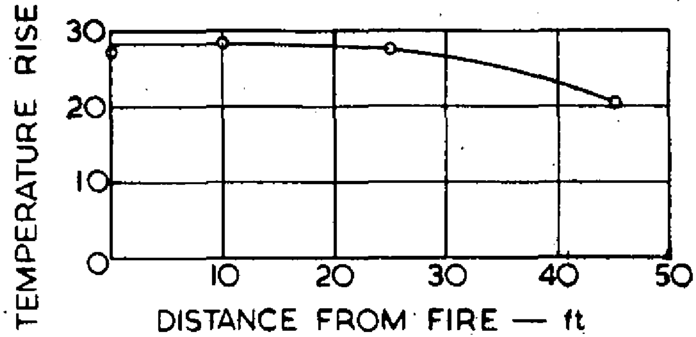
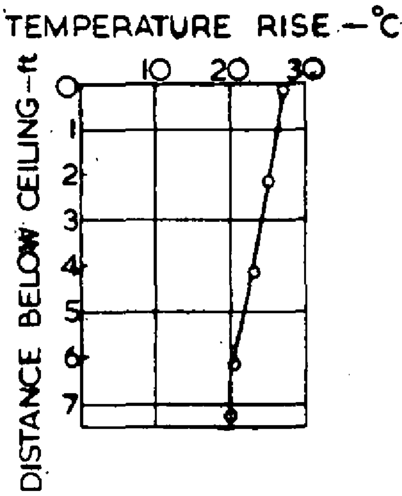
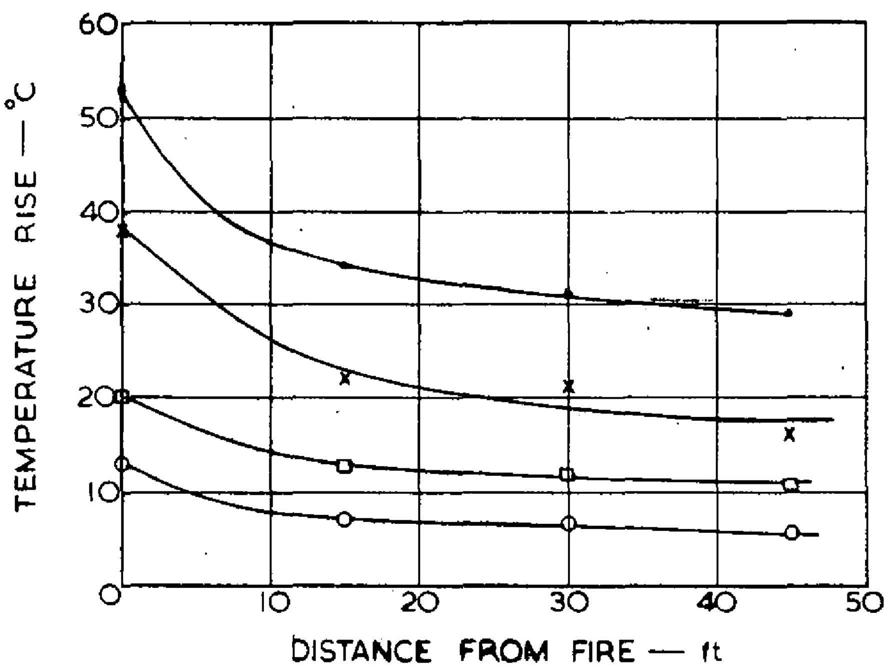




3ft dia. fire 31ft 3in. foam measuring point. (Convected heat output 60·0 Kcal/s)

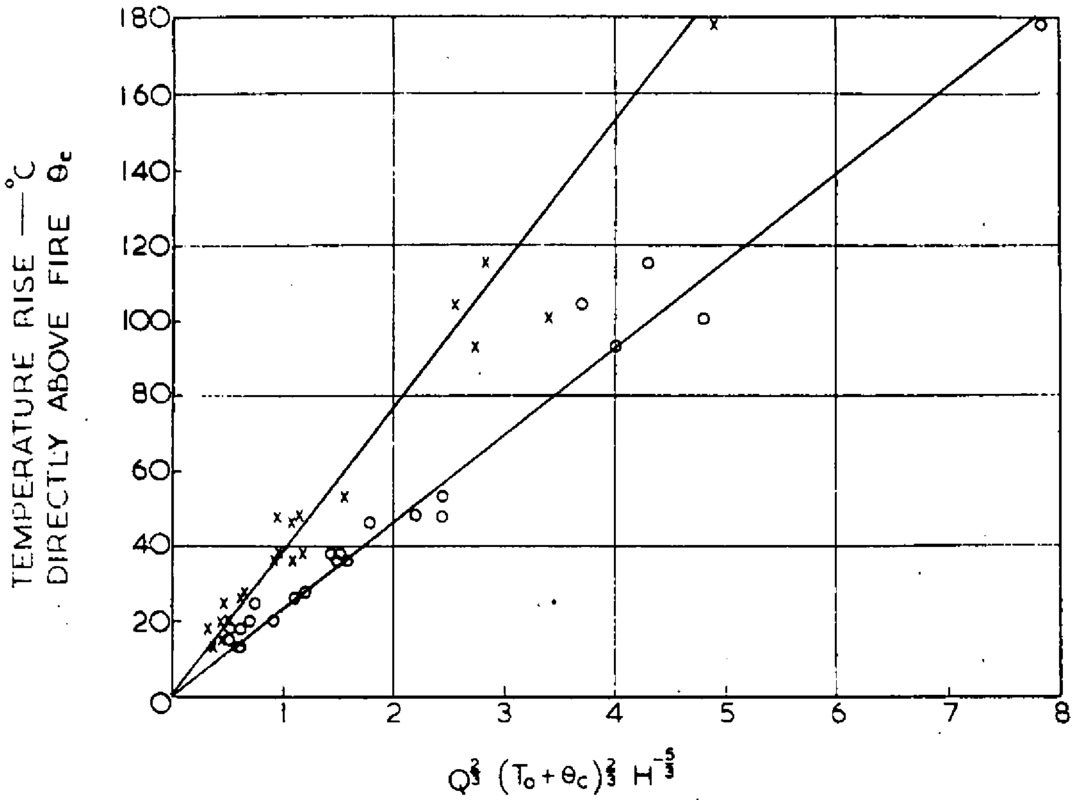
FIG. 20. TEMPERATURE RISE 2in. BELOW FLAT CEILING OF LARGE BUILDING AND TEMPERATURE RISE PROFILE. TEST No. 17.



Distance from fire to couple — 38 ft

		Estimated convected heat output — Kcal/s
Test No. 18	3ft dia. meths fire	60
Test No. 19	14 lb wood crib	42
Test No. 20	60 lb wood crib	180
Test No. 21	120 lb wood crib	360

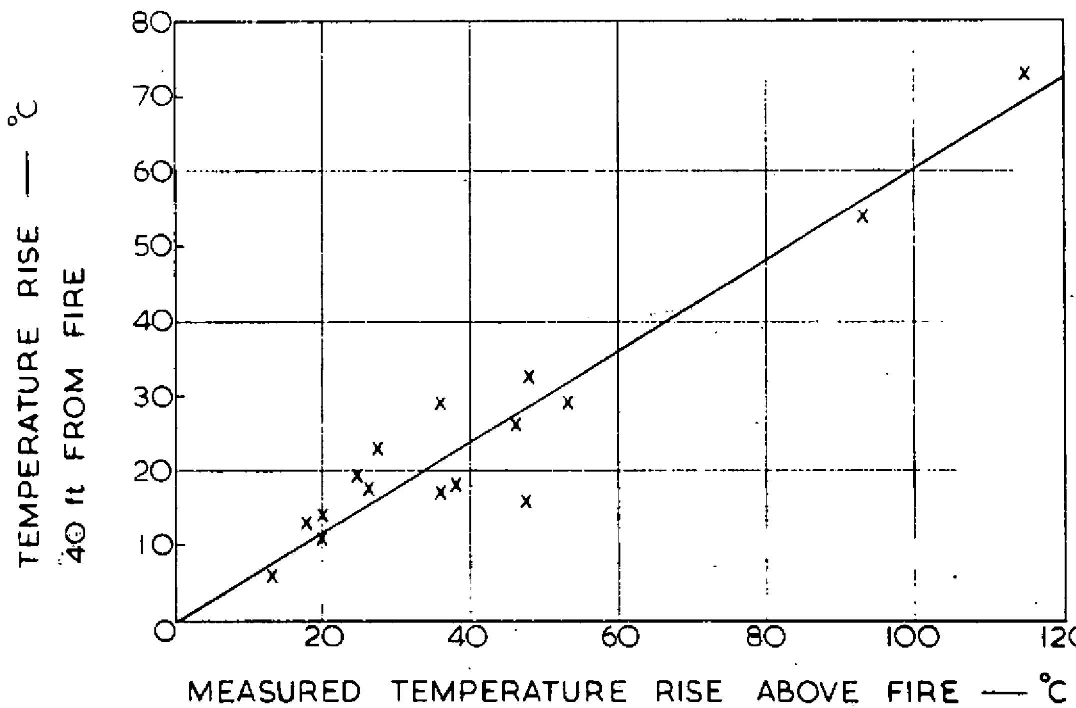
FIG. 21. TEMPERATURE RISE 11in. BELOW CEILING OF LARGE BUILDING, WITH JOISTED CEILING TESTS 18, 19, 20, 21



x——x H - distance from point source to ceiling (h + 1·3 d)

o——o H - distance from point source to ceiling minus depth of hot layer (h + 1·3d − D)

FIG. 22. CORRELATION OF TEMPERATURES DIRECTLY ABOVE FIRE



x——x Theoretical line for mixed temperature — $\theta_M = 0{\cdot}6\ \theta_c$

FIG. 23. TEMPERATURE RISE AT A DISTANCE FROM THE FIRE AS A FUNCTION OF TEMPERATURE RISE ABOVE FIRE

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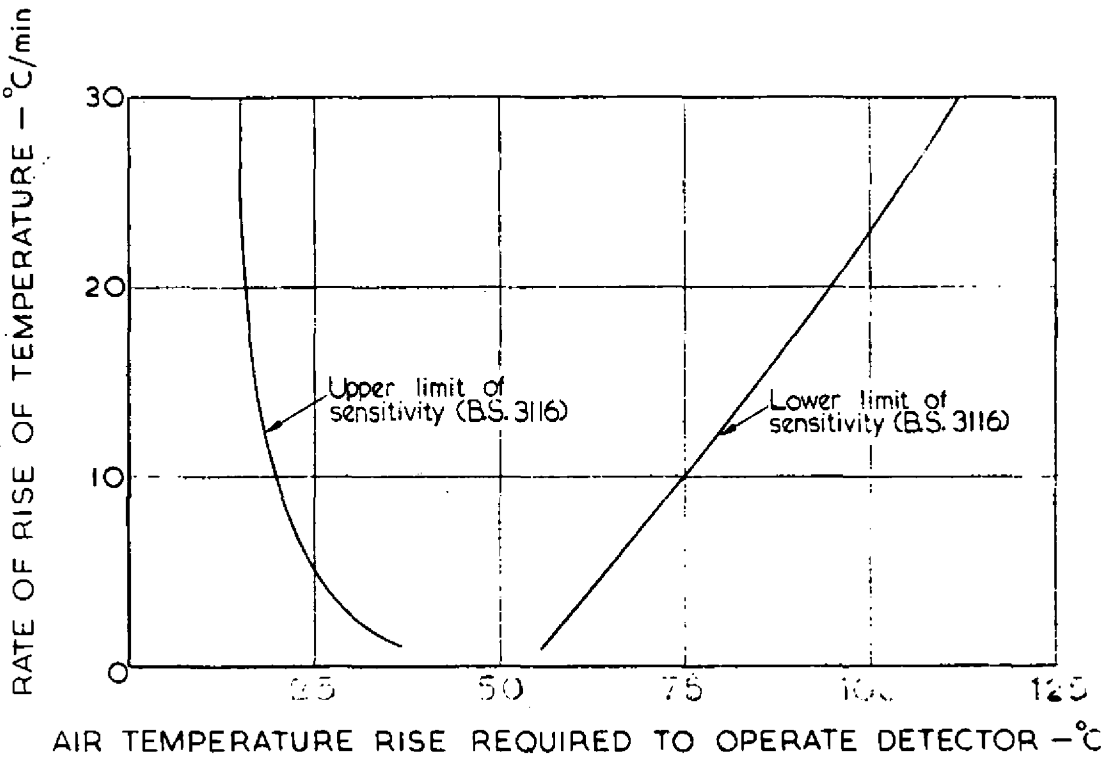

FIG. 24. TEMPERATURE RISE OF AIR STREAM WHEN DETECTORS OPERATE

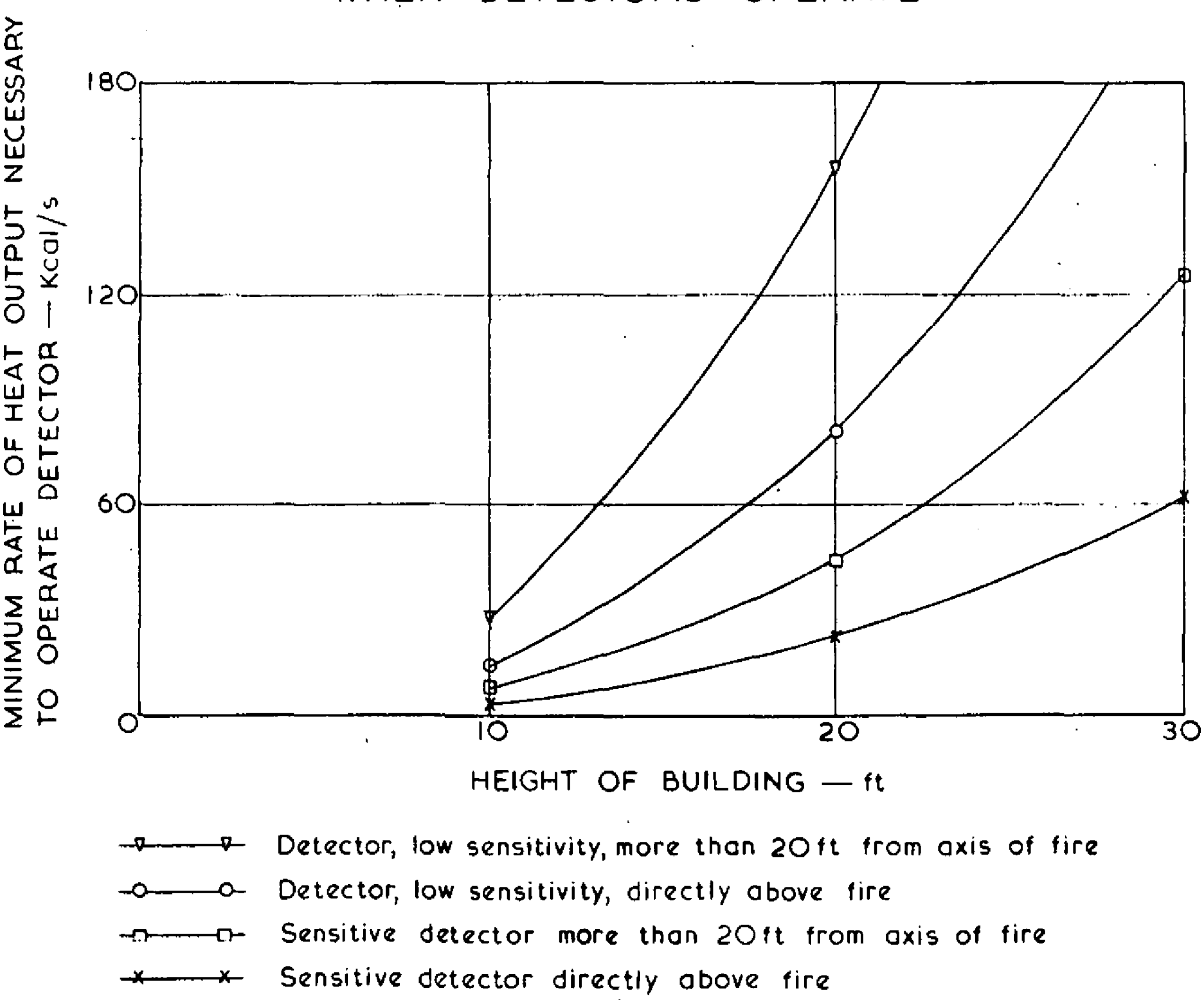

FIG. 25. MINIMUM RATE OF HEAT OUTPUT NECESSARY TO OPERATE DETECTORS OF DIFFERING SENSITIVITIES WITH SLOWLY DEVELOPING FIRE — 5°C/min

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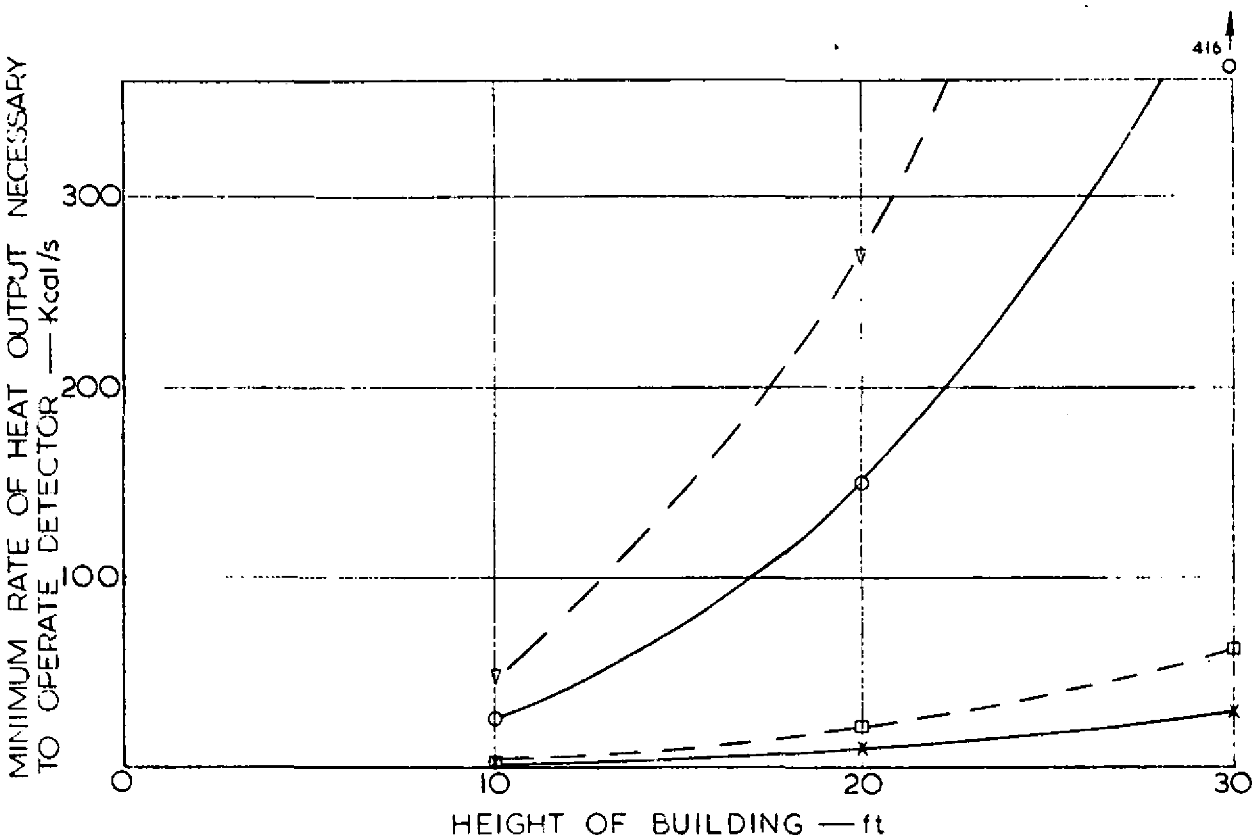
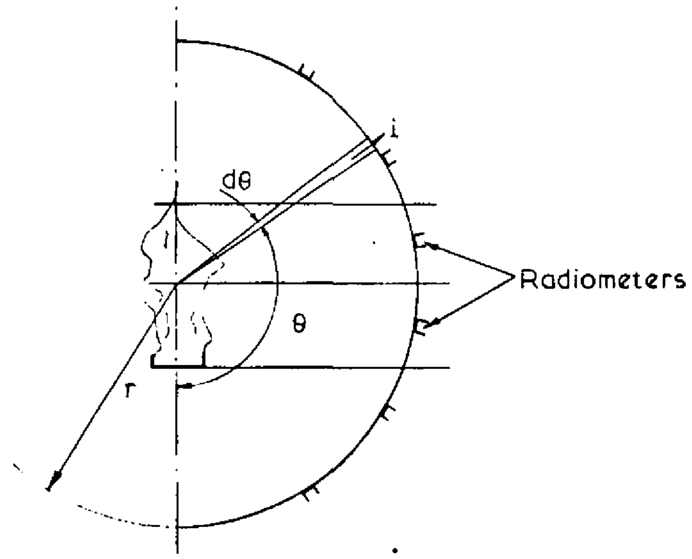


Detector, low sensitivity more than 20 ft from axis of fire
Detector, low sensitivity directly above fire
Detector, high sensitivity more than 20 ft from axis of fire
Detector, high sensitivity directly above fire

FIG. 26. MINIMUM RATE OF HEAT OUTPUT NECESSARY TO OPERATE DETECTORS OF DIFFERING SENSITIVITIES WITH RAPIDLY DEVELOPING FIRE— 25 °C/min



Apparatus for measuring radiation

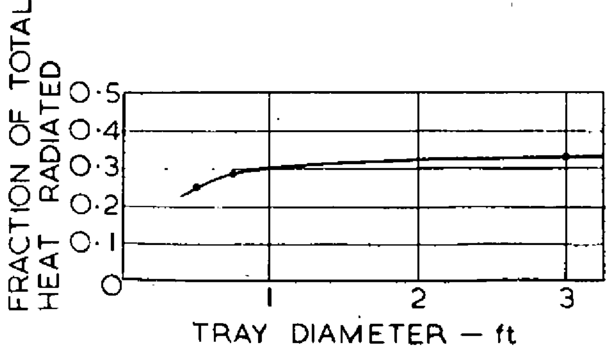


FIG. 27. MEASUREMENT OF RADIATION